RECONSIDERATION OF INJURY CRITERIA FOR PEDESTRIAN SUBSYSTEM LEGFORM TEST - PROBLEMS OF RIGID LEGFORM IMPACTOR -

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ABSTRACT

The legform impactor proposed by EEVC/WG17 [1] is composed of a rigid thigh segment and a rigid lower leg segment. Human bone, however, has flexibility, causing some differences between the EEVC rigid legform impactor and the human leg. This research analyzes the influence of the differences (rigid versus flexible) on the injury criteria. It also reanalyzes the upper tibia acceleration with regard to the fracture index.

The rigid legform impactor cannot simulate bone bending motion, so the injury criteria should consider the legform rigidity. It means the injury criteria need to include the bone bending effect. From several PMHS test results, the shearing displacement becomes 23mm and 20 degrees for bending angle including the bone bending effect. However, the bone bending effect will change with the loading conditions. Therefore, to establish a certain injury criteria for a rigid legform impactor is impossible. To solve this problem, a flexible legform impactor seems to be needed. If a flexible legform impactor exists, the relationship between rigid bone and flexible bone need not be considered, and the pure ligament tolerance can be applied.

The threshold of upper tibia acceleration as for lower leg fracture (fibula/tibia/tibia+fibula fracture) was found to be 198G for 50% injury risk, but if we focus on the tibia fracture (tibia/tibia+fibula fracture), exclude the fibula-only fracture cases, the threshold becomes 247G.

By the way, to use only the upper tibia acceleration as the leg fracture index is a problem. The relationship between upper tibia acceleration and fracture was obtained from a PMHS test series which were conducted normal bumper height, but if the impact point is changed, the upper tibia acceleration becomes lower but the leg fracture occurs. Therefore, if the acceleration use for the leg fracture index, the accelerometer should be attached proper position. More the worse, the tibia acceleration from the rigid impactor is completely different from human leg because of its rigidity. Therefore, the acceleration from a rigid legform impactor should not be used for the estimation. If the legform impactor is flexible, the acceleration becomes proper, and can be made proper estimation.

Finally, a flexible legform impactor seems to be needed for proper estimation of leg injury.

INTRODUCTION

A subsystem test procedure with a legform impactor has been proposed by EEVC/WG17 to address leg injuries in car-pedestrian accidents. However, the proposed legform impactor is composed of a rigid thigh segment and a rigid lower leg segment. The legform impactor therefore cannot simulate the bone-bending motion of the human leg, and the difference seems to affect the test results and the injury criteria.

This research investigates the influence of the legform impactor rigidity on the injury criteria. Furthermore, the problem of the upper tibia acceleration as an injury criterion is analyzed.

INFLUENCE OF BONE RIGIDNESS ON THE KNEE INJURY CRITERIA

Figure 1 shows the concept of the EEVC/WG17 legform. The knee part of the legform impactor can be moved in the shearing and bending directions, and the shearing displacement and bending angle are established as injury criteria.
Kajzer et al. [2][3] conducted several dynamic PMHS tests to obtain the human knee characteristics versus shearing and bending mode. Figure 2 shows the test setups and Table 1 shows the test results. This research applied a logistic analysis method [4] to the test results and obtained the injury risk curve against the shearing displacement and the bending angle as shown in Figure 3. From the risk curve, the shearing displacement is 24.2mm at 50% injury risk, and 19.8 degrees for the bending angle.

Ramet et al. [5] conducted several similar tests under quasi-static loading. Figure 4 shows the test setup and Table 2 shows the test results. Same as above, logistic analysis applied to the test results, and obtained the injury risk curves. Figure 5 shows the injury risk curve. From the risk curve, the shearing displacement is 22.7mm and 21.8 degrees for the bending angle.

The injury criteria from the dynamic test and the quasi-static test were comparable, and from these injury risk curves, the injury criteria could be set as 23mm for shearing displacement and 20 degrees for bending angle. However, these values seem too large just as for the ligament tolerance. To make clear this reason, FE-Lower limb model was used.

Figure 6 shows the FE-Lower limb model. This model was validated with many kinds of PMHS test results, and the validation results were presented at STAPP 2000[6]. Figure 7 shows the bone bending motion in the shearing test and bending test. The bending motion works as for increasing the injury criteria as shown in Figure 8. The injury criteria include ligament elongation and bone bending effect.

However, the bone bending effect on the injury criteria will change with impact conditions, therefore it is impossible to establish an injury tolerance for a rigid legform impactor in the end. Then how to solve this problem. It is clear that the difference between rigid bone and flexible bone as shown in Figure 9.

Finally, a flexible legform impactor seems to be needed. If a flexible legform is used, the relationship between rigid bone and flexible bone does not need to be considered, and pure ligament tolerance can be used.

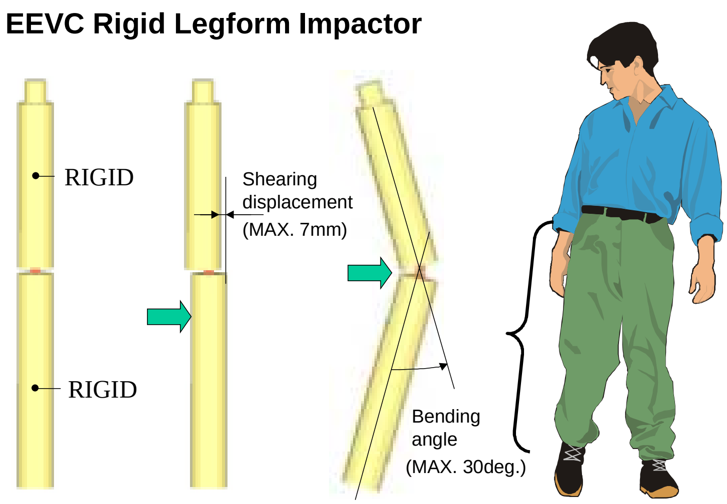
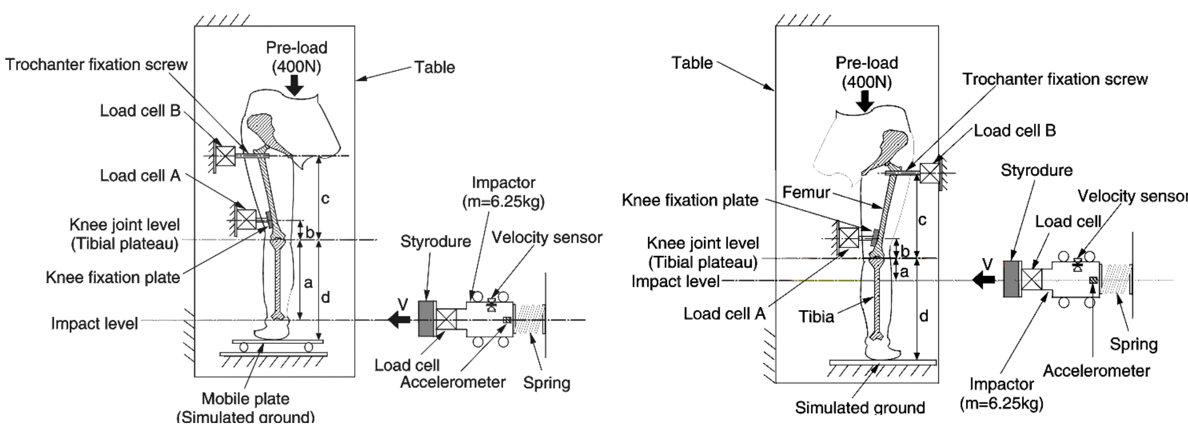


Figure 1. Specification of EEVC rigid legform impactor



(1) Shearing test (2) Bending test

Figure 2. Dynamic impactor test

Table 1. PMHS test results (Dynamic impact test)

Dynamic shearing test

Shearing displacement		
Test No.	Ligament No injury	Ligament Injury
4S	28	
5S*		31
8S	12	
9S	27	
12S	13	
13S	14	
16S		23
17S	26	
21S		21
28S		15
29S		13

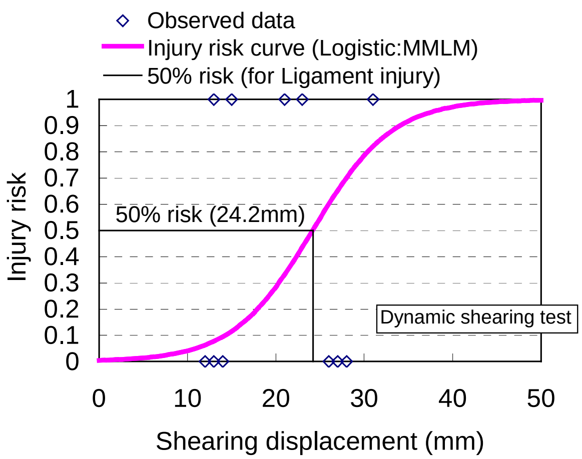
unit (mm)

* assumed the ligament injuy as initial damage.

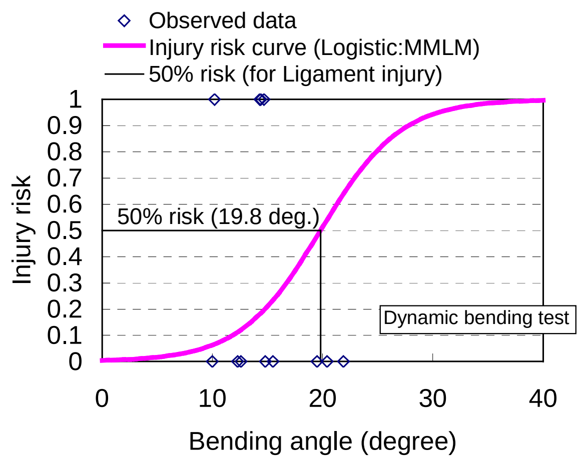
Dynamic bending test

Bending angle		
Test No.	Ligament No injury	Ligament Injury
2B	19.5	
3B		14.4
6B		14.7
7B	21.9	
10B	15.5	
11B	14.8	
14B	10.0	
15B	12.6	
18B	20.4	
22B	12.3	
27B		10.2
30B		14.3

unit (deg.)

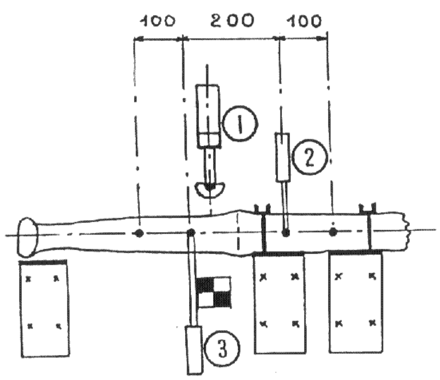


(1) Shearing displacement

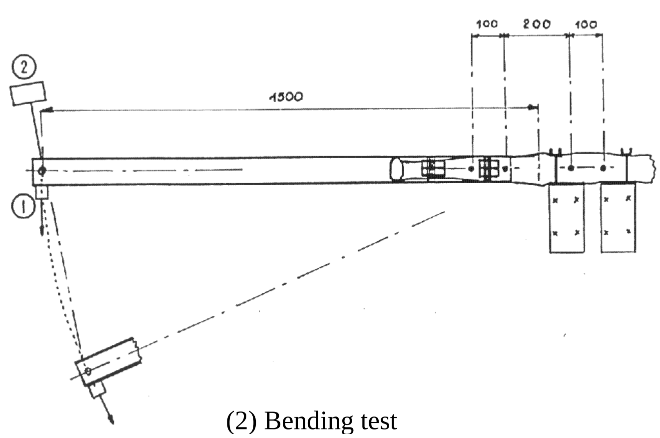


(2) Bending angle

Figure 3. Injury risk curve (Dynamic impact test)



(1) Shearing test



(2) Bending test

Figure 4. Quasi-static test

Table 2. PMHS test results (Quasi-static test)

Quasi-static shearing test

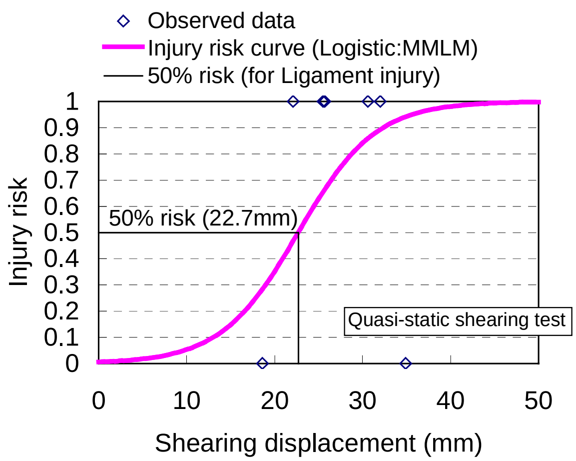
Shearing displacement		
Test No.	Ligament: No injury	Ligament: Injury
GCC04		30.6
GCC05	18.6	
GCC06	34.9	
GCC07		32.0
GCC08		25.5
GCC09		22.1
GCC10		25.7

unit (mm)

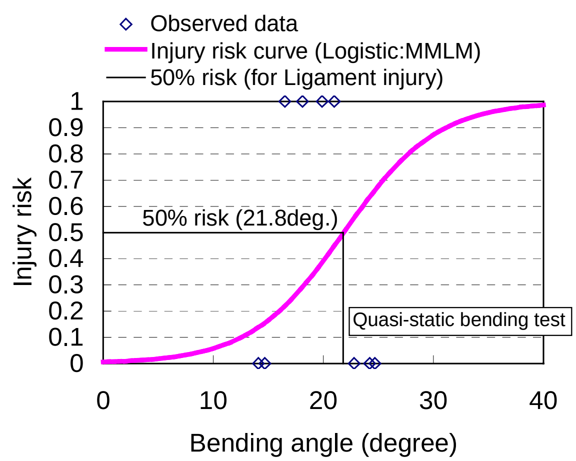
Quasi-static bending test

Bending angle		
Test No.	Ligament: No injury	Ligament: Injury
GPC11	14.1	
GPC12	14.7	
GPC21		16.5
GPC22		19.9
GPC31	24.2	
GPC32	22.8	
GPC41	24.7	
GPC42		21.0
GPC52		18.1

unit (deg.)



(1) Shearing displacement



(2) Bending angle

Figure 5. Injury risk curve (Quasi-static test)

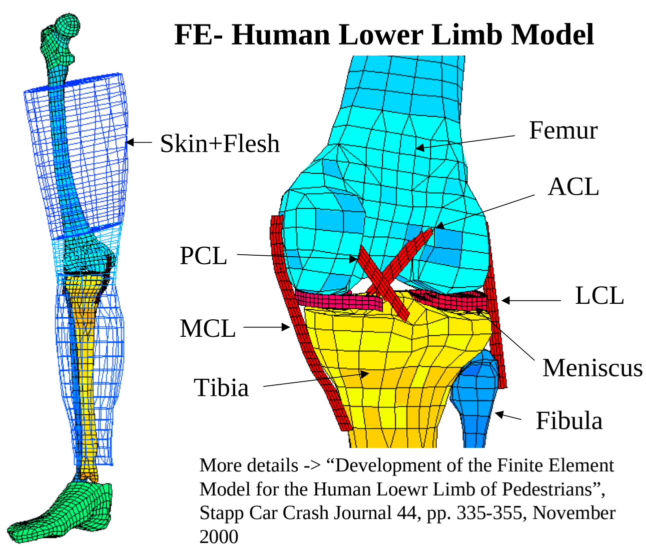
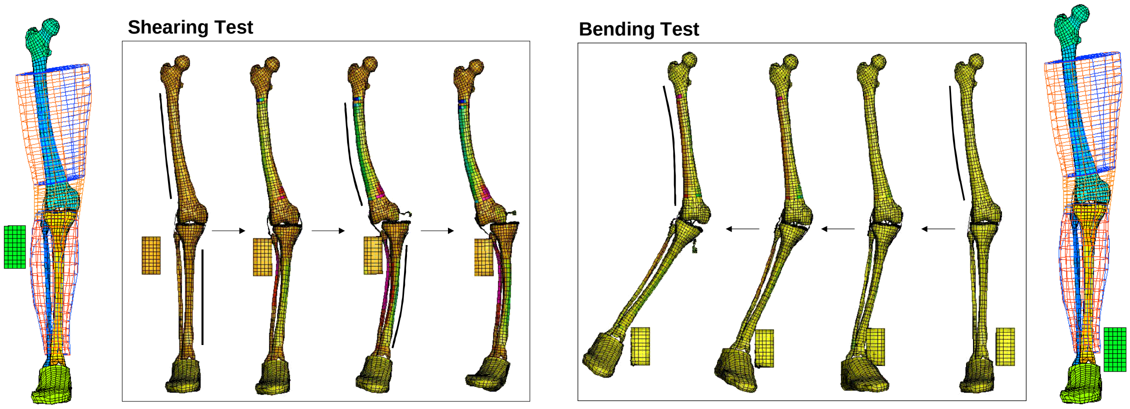


Figure 6. FE-Human lower limb model



(1) Shearing test (2) Bending test

Figure 7. Bone bending motion

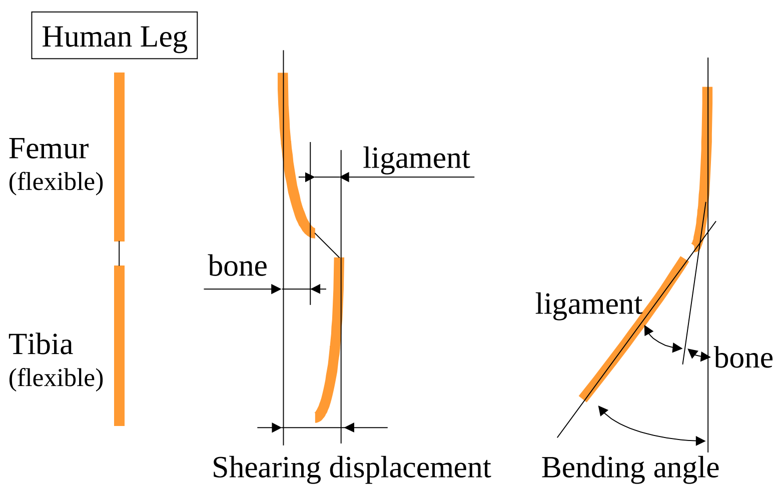


Figure 8. Bone bending effect against shearing displacement and bending angle.

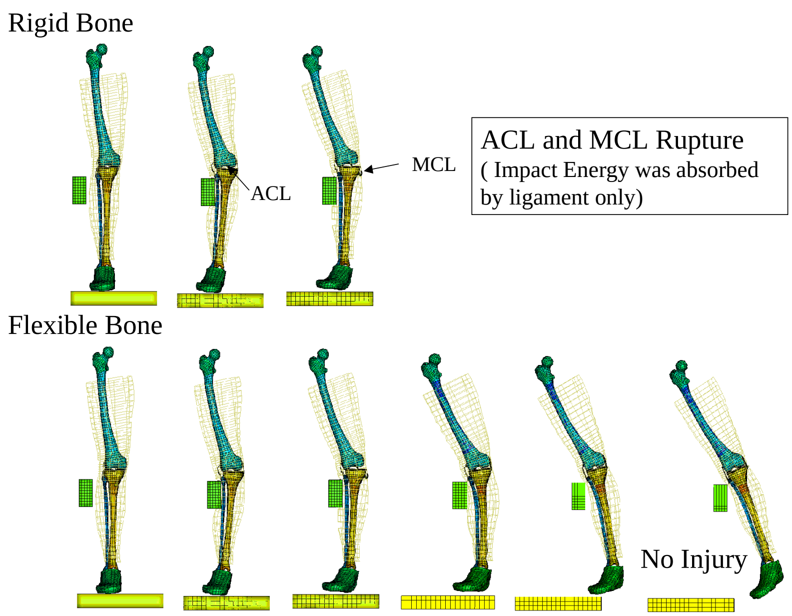


Figure 9. Difference of Injury between rigid bone and flexible bone

REANALYSIS OF THE TIBIA ACCELERATION AS FOR AN INDEX OF LOWER-LEG FRACTURE

The rigid EEVC legform impactor estimates the possibility of lower leg fracture by using upper tibia acceleration. The relationship between the acceleration and fracture is obtained from a PMHS test series conducted by Bunketorp et al. [7]. Figure 10 shows the test setup and Table 3 shows the test results. The acceleration was measured at the impact point level. Figure 11 shows the injury risk curve. From the injury risk curve, the lower leg fracture (fibula/tibia/tibia+fibula fracture) risk is 198G for 50% injury risk. The result is comparable to the EEVC/WG17 results (190G at 50% injury risk).

However, the base data includes the fibula-only fracture cases. As shown in Figure 12, the fibula receives the initial impact and breaks easily because of its location, however, the injury level of fibula fracture is relatively low (AIS2 maximum). In contrast, tibia fractures may become AIS3, and most tibia fractures accompany with fibula fracture as shown in Figure 13 and Table 3. Figure 14 shows the injury risk curve of the tibia fracture (tibia/tiba+fibula fracture). From the curve, the tibia tolerance is 247G at 50% risk. If tibia protection is provided for the first phase of pedestrian leg protection, the injury criteria can be set as 240G or so.

By the way, there is a problem in using only upper tibia acceleration for the tibia fracture index. The relationship between tibia acceleration and fracture was obtained from a PMHS test series in which the impact condition is normal bumper height and the acceleration is measured at upper part of the tibia. However, when the impact point was changed as shown in Figure 15, tibia fracture occurs even if the upper tibia acceleration is small. Therefore, when the tibia acceleration is used for the leg injury criterion, the measurement point of tibia acceleration should be changes to a proper position by each test.

However, the acceleration from a rigid legform impactor is not comparable to the human one because of its rigidity. Figure 16 shows the difference of tibia acceleration between human leg and rigid legform impactor. In case of the rigid legform impactor, the highest acceleration occurs at the lowest measurement point, but this phenomenon is never observed in PMHS tests. In the PMHS test, the acceleration of lowest measurement point (ankle) is much lower than that of the impact level acceleration because of the leg flexibility [7]. More the worse, the difference affects the acceleration itself as shown in Figure17. The rebound of the rigid legform becomes higher than the flexible one, so the acceleration of rigid legform impactor becomes higher than the flexible one. Therefore even the same measurement point, the acceleration differs between human leg and rigid legform impactor. Therefore, the tibia acceleration of rigid legform impactor cannot be used for proper estimation. If a flexible legform impactor is used, the acceleration would be appropriate, and an appropriate estimate could be made.

Finally, the same conclusion was obtained as before section. A flexible legform impactor seems to be needed for proper estimation of leg injury.

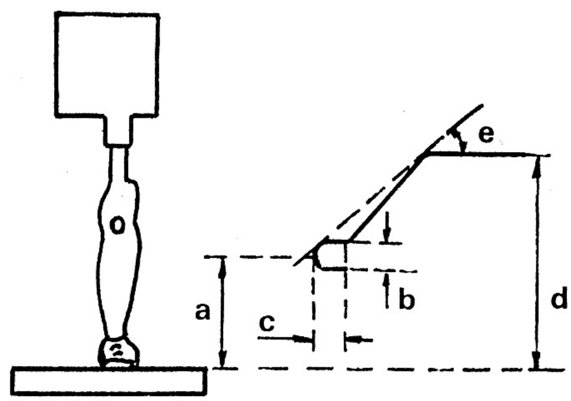


Figure 10. Dynamic bumper test

Table 3. PMHS test results (Dynamic bumper test)

Dynamic bumper test

Test No.	Tibia acceleration: Lower leg: fibula	tibia	tibia+fibula	No injury
A01		230		
A02				260
A03			285	
A04				295
A05				245
A06			95	
A07				85
A08				70
A09				85
A10				100
A11			225	
A12			275	
A13			200	
A14			270	
A15	280			
A16				70
A17				80
A18	115			
A19				120
A20				80

unit (G)

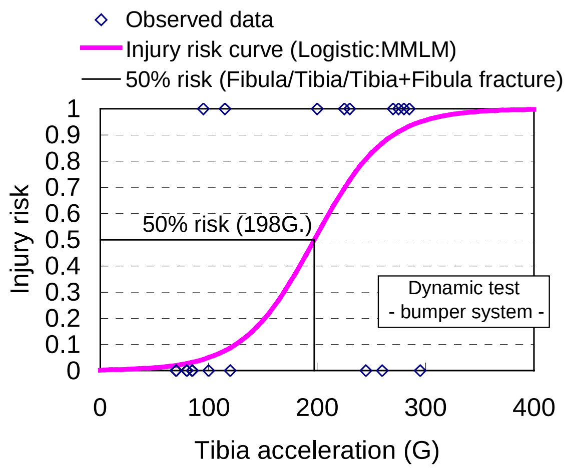


Figure 11. Injury risk (Fibula/Tibia/Tibia+Fibula fracture)

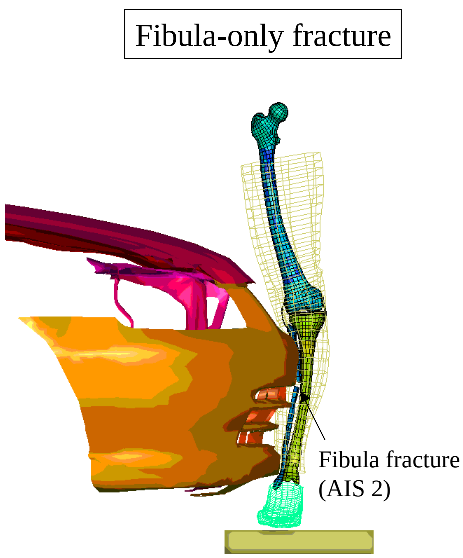


Figure 12. Fibula-only fracture

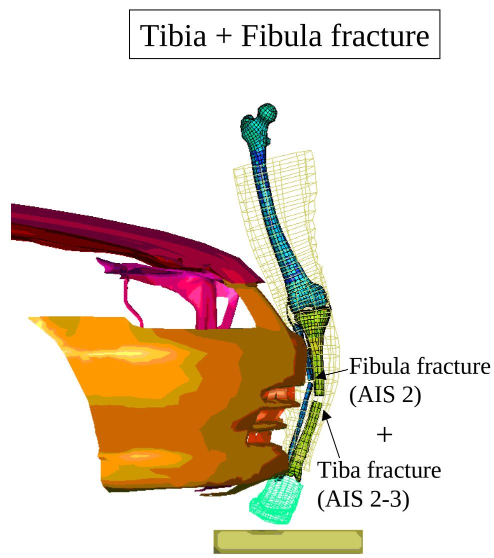


Figure 13. Tibia+Fibula fracture

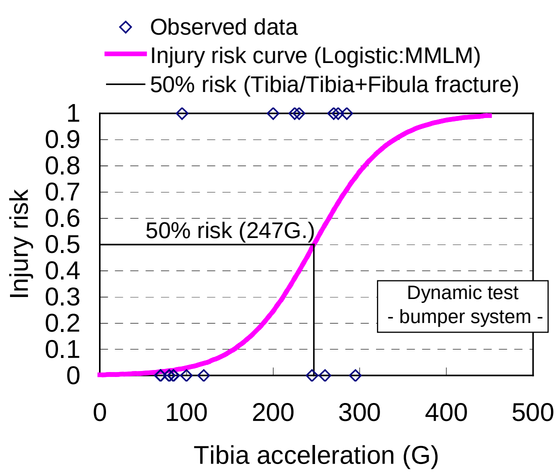
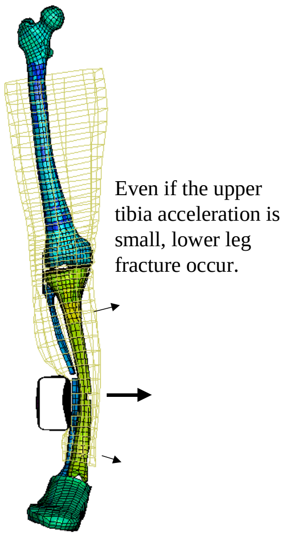


Figure 14. Injury risk (Tibia/Tibia+Fibula fracture)



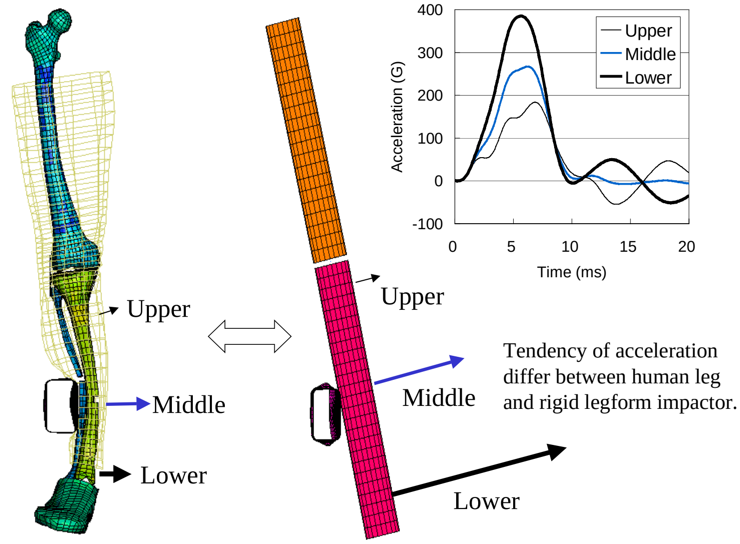


Figure 15. Relation ship between tibia upper acceleration and tibia fracture

Figure 16. Difference of the tendency of the tibia acceleration

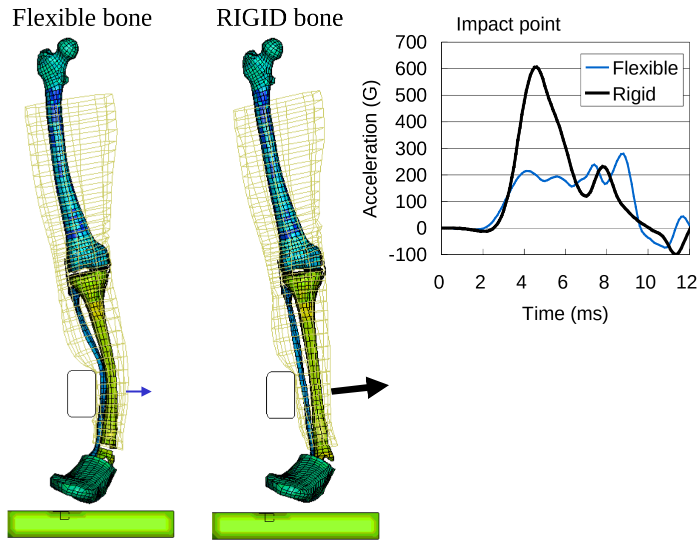


Figure 17. Difference of tibia acceleration at the impact point

CONCLUSION

(1) The injury criteria of rigid legform impactor, which are obtained from PMHS tests, is 23mm for the shearing displacement and 20 degrees for the bending angle. The values include the bone bending effect.
(2) However, the bone bending effect will vary with the impact conditions. As a result, it is impossible to establish a certain injury criteria for a rigid legform impactor. If a flexible legform impactor exists, the relationship between rigid bone and flexible bone need not to be considered, and the pure ligament tolerance can be used.
(3) The threshold of the lower leg fracture (fibula/tibia/tibia+fibula fracture) is 198G, but if we focus on the tibia fracture (tibia/tibia+fibula fracture) , excluding the fibula-only fracture, for the first phase of pedestrian leg protection, the injury threshold could be 240G or so.
(4) It is inappropriate to estimate the tibia fracture by using only the upper tibia acceleration. When the impact point is changed, the tibia fracture occurs, even if the upper tibia acceleration is small. To estimate tibia fracture properly, the measurement point of tibia acceleration should be change to a proper position.
(5) However, acceleration from a rigid legform impactor differs with human leg one because of its rigidity, so the acceleration from rigid legform impactor should not to be used for the estimation. If a flexible legform impactor is used, the acceleration becomes proper and can be used for proper estimation.
(6) Finally, a flexible legform impactor seems to be needed for proper estimation of leg injury.

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